# EXHIBIT 11


# HTTP Adaptive Streaming in practice

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(with thanks to the Netflix adaptive streaming team!)

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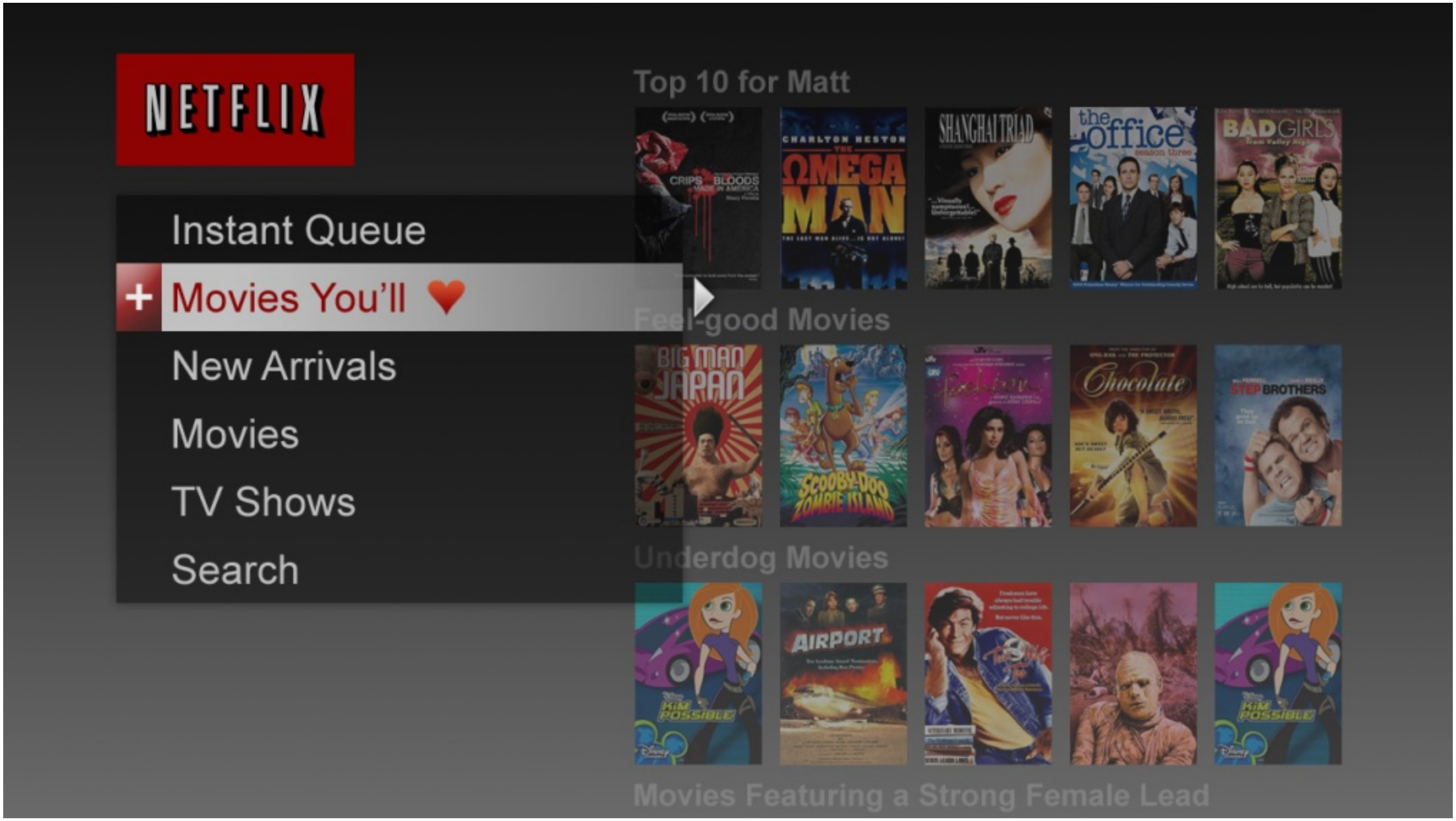
# Netflix Overview


*Netflix corporate headquarters*
*Los Gatos, California*

- Started with DVD-by-mail,
  **now primarily Internet streaming**
- **20+ million[1] subscribers,**
  **growing rapidly** *(>15% of US households subscribe to Netflix)*
- USA-only for ten years,
  Canada in 2010,
  further expansion in 2011+
- Unlimited Streaming = $7.99/month
  - Plus 1 DVD at a time = $9.99/month

[1] subscriber reported 1/26/11

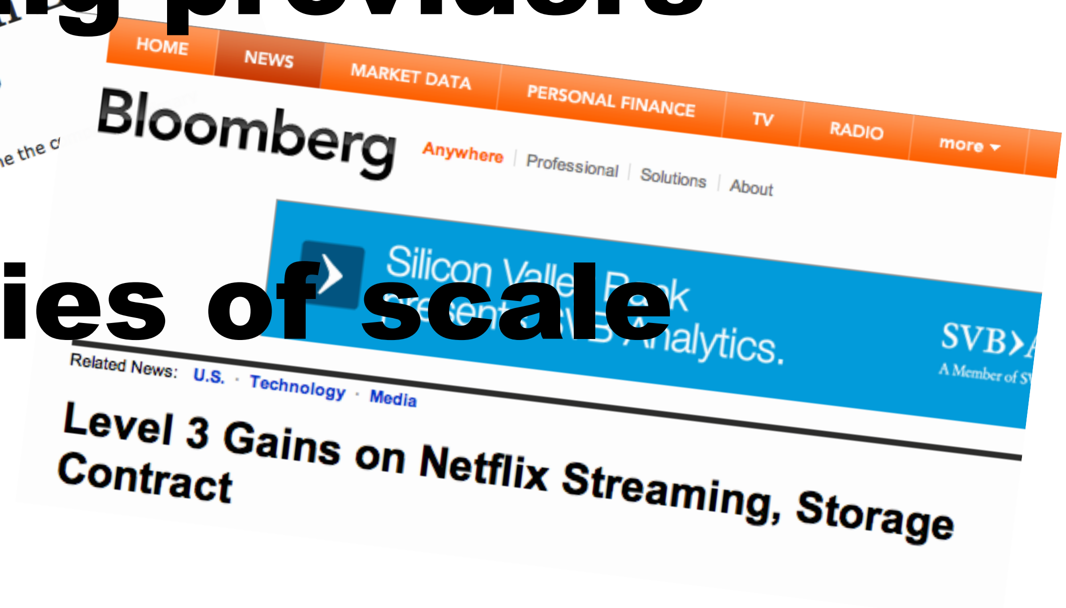
# Partner Products


NETFLIX
Top 10 for Matt
Instant Queue
Movies You'll
New Arrivals
Movies
TV Shows
Search
Feel-good Movies
Underdog Movies
Movies Featuring a Strong Female Lead

# Contents

- Why HTTP adaptive streaming ?
- Streaming approaches
- Measuring quality and the value of quality
- Adaptation algorithms and open problems

# Why HTTP Adaptive Streaming ?

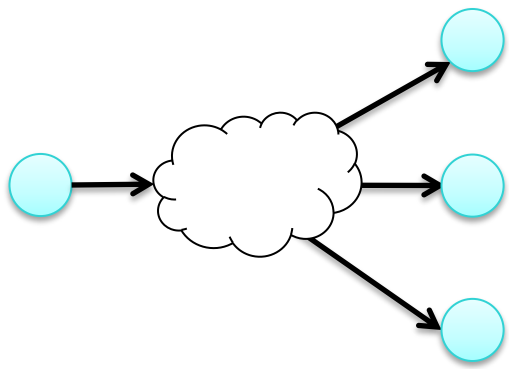

**Commodity service**

**Competing providers**

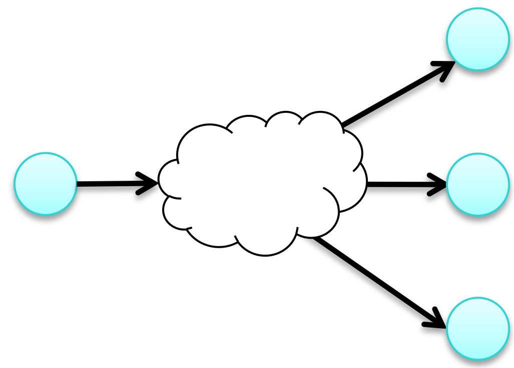
**Economies of scale**

Unicast

Multicast



Synchronous



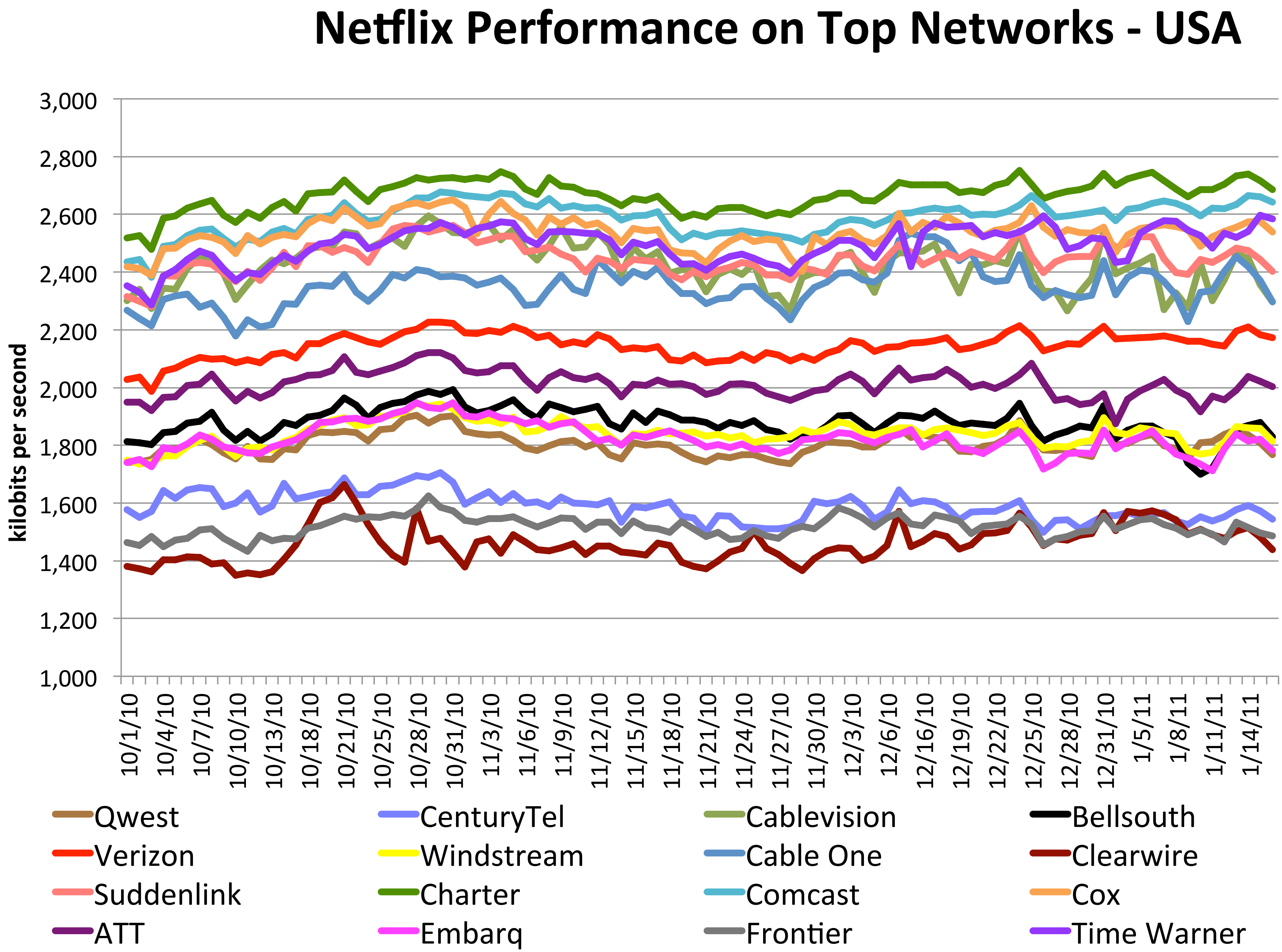
Asynchronous

# Client-centric approach

- Client has the best view of network conditions
- No session state in network
  - Redundancy
  - Scalability
- Faster innovation and experimentation
- BUT, relies on client for operational metrics
  - only the client knows what really happened anyway

# Scalability examples

- Microsoft streaming of 2008 Olympics
  - 4 Petabytes live & VoD content in one month
  - North America (av. user bandwidth 2Mbit/s)
  - Millions of simultaneous sessions
  - **Over existing infrastructure**
- Netflix
  - 20% of North American Internet traffic at peak hours
  - Millions of hours of content every day
  - Bitrates up to 4.8Mbit/s
  - Almost no dedicated infrastructure
    - Control servers in AWS
    - Content delivery through CDNs



Netflix Performance on Top Networks - USA
kilobits per second
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
10/1/10
10/4/10
10/7/10
10/10/10
10/13/10
10/18/10
10/21/10
10/25/10
10/28/10
10/31/10
11/3/10
11/6/10
11/9/10
11/12/10
11/15/10
11/18/10
11/21/10
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11/27/10
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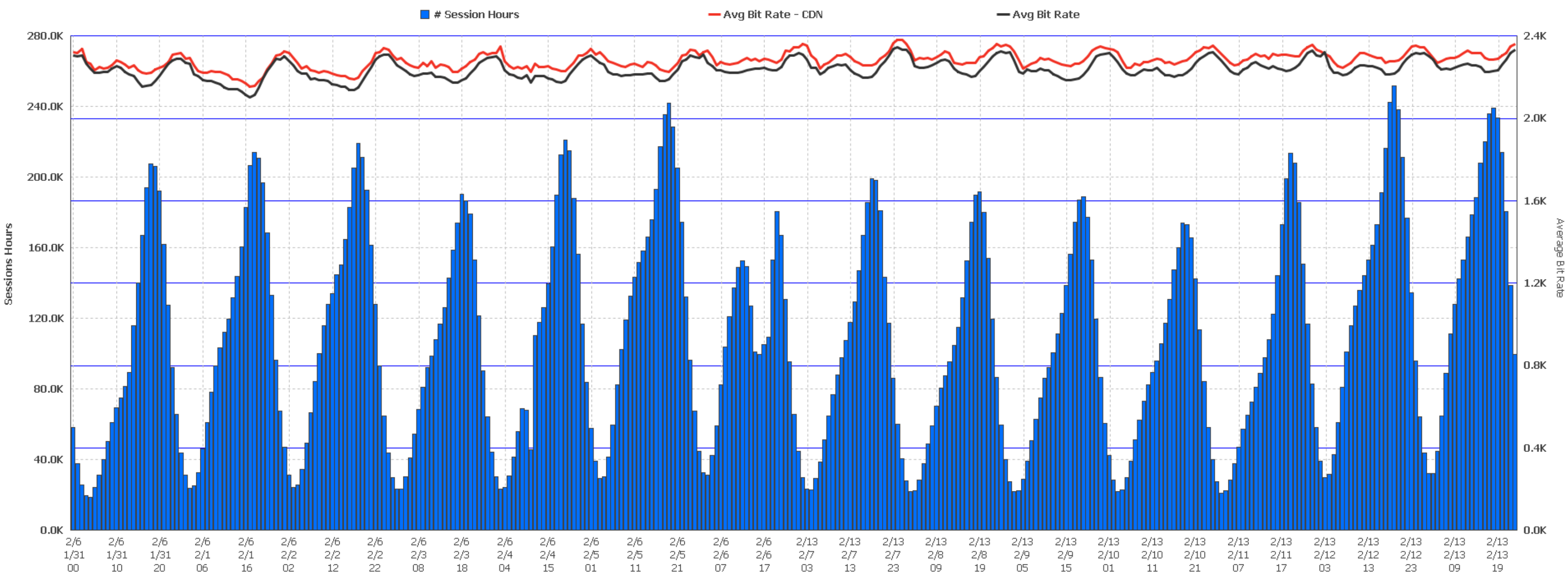
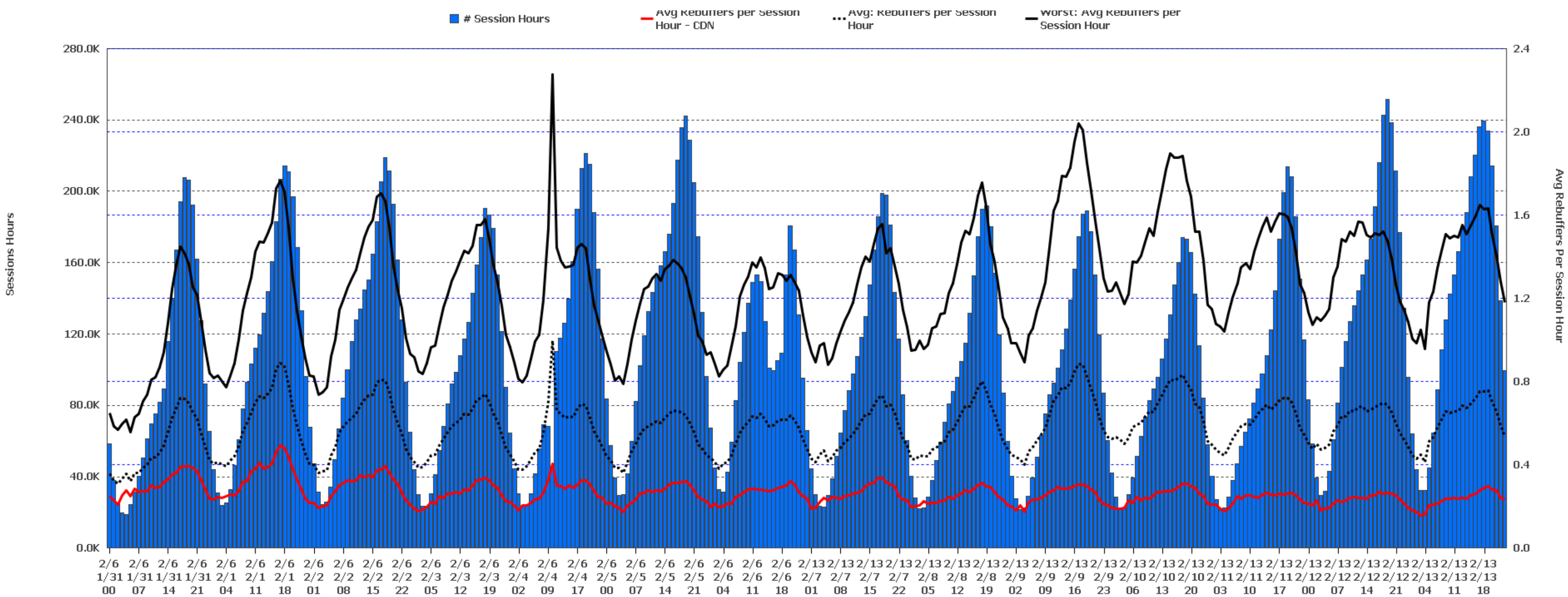
12/3/10
12/6/10
12/16/10
12/19/10
12/22/10
12/25/10
12/28/10
12/31/10
1/5/11
1/8/11
1/11/11
1/14/11
Qwest
CenturyTel
Cablevision
Bellsouth
Verizon
Windstream
Cable One
Clearwire
Suddenlink
Charter
Comcast
Cox
ATT
Embarq
Frontier
Time Warner

# Streaming bitrate performance




(just one device type)

# Streaming rebuffer rates

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# Adaptive streaming in practice

move networks, inc.

HTTP Live Streaming

Small media chunks
("streamlets")

Microsoft Silverlight

Smooth Streaming

Adobe HTTP Dynamic
Streaming

Chunks created at
origin server

NETFLIX


MPEG DASH

HTTP Byte Range
requests

# Adaptive streaming in practice

move networks, inc.

HTTP Live Streaming

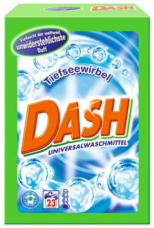
Combined A/V streams only

Microsoft Silverlight

Smooth Streaming

Adobe HTTP Dynamic Streaming

NETFLIX




MPEG DASH

Separate Audio/Video

# Adaptive streaming in practice

move networks, inc.

HTTP Live Streaming

No switchpoint alignment

Microsoft Silverlight

Smooth Streaming

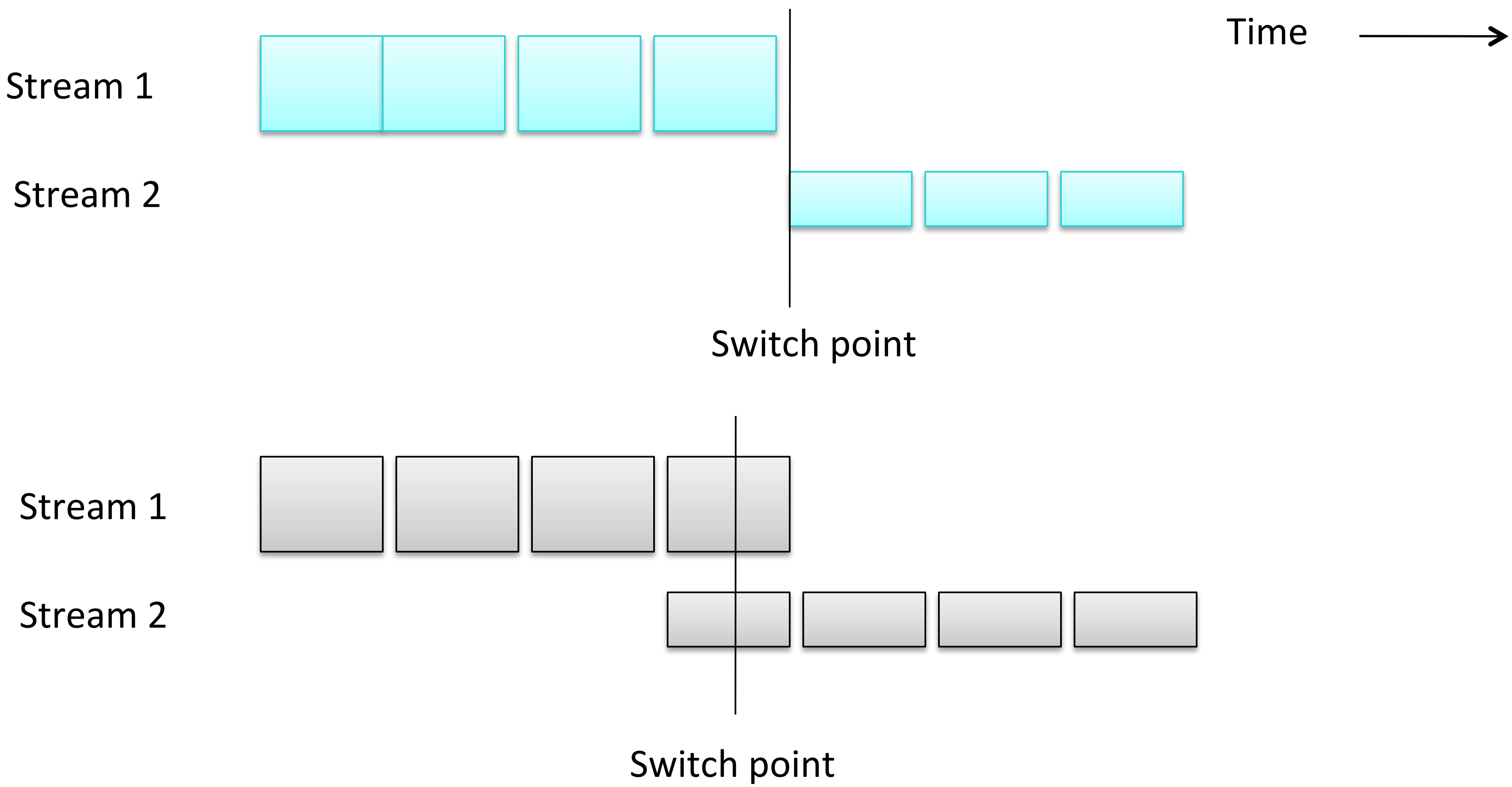
Adobe HTTP Dynamic Streaming

NETFLIX


MPEG DASH

Switchpoint alignment (optional)

# Switchpoint Alignment



# Adaptive streaming summary

- For On Demand
  - Chunks are unnecessary and costly
  - Byte Range requests have caching and flexibility advantages
  - Separate audio/video essential for language support
- For Live
  - Chunks are unavoidable
  - Still value in decoupling request size from chunk size
  - Multiple language audio tracks are rare
  - May need manifest updates
- For both
  - Switch point alignment required for most CE decoding pipelines

# MPEG DASH

- Supports both unchunked & chunked
- Supports both separate & combined A/V
- Index formats for efficient byte range operation
- ISO Base Media File Format w/common encryption
- Rigorous definition of stream alignment requirements
- Signaling of different alignment modes
- Many useful stream and track annotations

**Currently the best candidate for an open standard for adaptive streaming**

# Contents


- Why HTTP adaptive streaming ?
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- **Measuring quality and the value of quality**
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# Measuring quality

- Reliable transport => all-or-nothing delivery
- Quality characterized by
  - Video quality
    - At startup, average and variability
  - Re-buffer rate
    - Re-buffers per viewing hour, duration of re-buffer pauses
  - Startup delay
    - Time from use action to first frame displayed

# Importance of client metrics

- Metrics are operationally essential
  - Detecting and debugging failures
  - Managing performance
  - Experimentation
- Absence of server-side metrics places onus on client
- What do we need ?
  - Reports of what the user did (or didn't) see
    - Which part of which stream presented when
  - Reports of what happened on the network
    - Requests sent, responses received, timing, throughput

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# Adaptation problem

**Choose sequence and timing of requests**

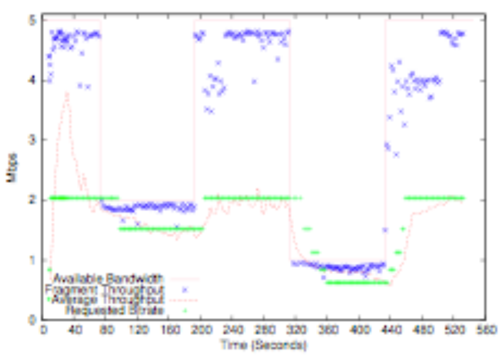
to

**Minimize probability of re-buffers**

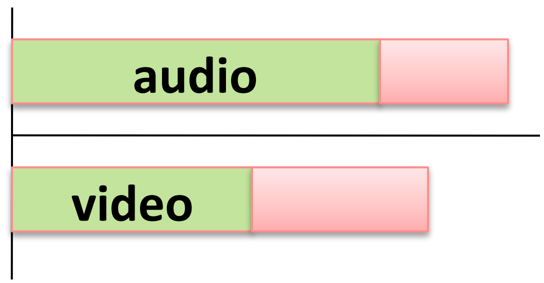
**Maximize quality**

# Adaptation problem: Inputs

History

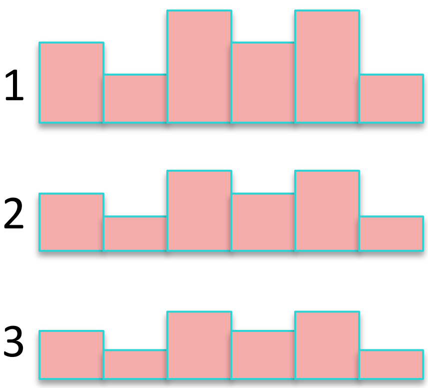


Current state




Possible choices

Stream 1
Stream 2
Stream 3



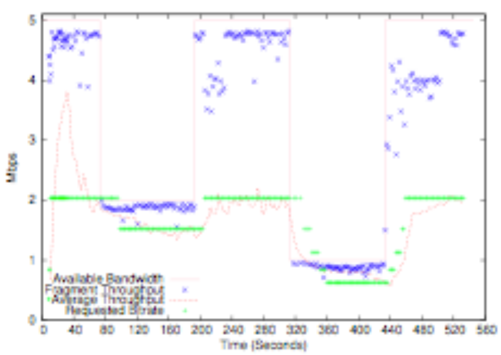
**Capturing and representing all this information is not easy!**

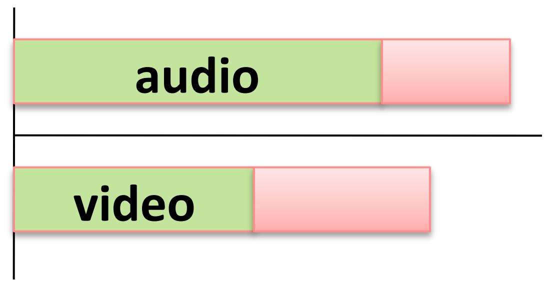
# Adaptation problem: logic

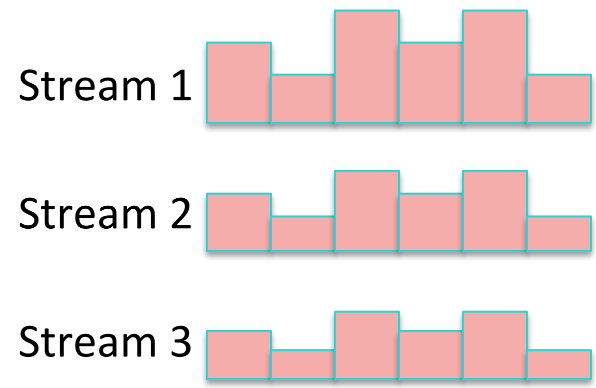
History

Current state

Possible choices




Model of future bandwidth

Expected performance for each choice

# Adaptation problem: example

- Model of future bandwidth
  - Constant
  - Equal to average over last 10s
- Analysis of choices
  - Construct "plan" for each choice
  - Determine re-buffers for each plan

# Adaptation problem: future work

- Good models of future bandwidth based on history
  - Short term history
  - Long term history (across multiple sessions)
- Tractable representations of future choices
  - Including scalability, multiple streams
- Convolution of future bandwidth models with possible plans

# Conclusions

- Asynchronous delivery of same content to many users is a first-class network service
  - HTTP CDNs may not be the "perfect" architecture, but it's working pretty well at scale
- Many variations on HTTP Adaptive Streaming theme in deployed systems and emerging standards
  - MPEG DASH provides sufficient flexibility here
- Adaptation is not straightforward
  - How to model bandwidth future based on history ?
  - How to efficiently search choice space to maximise quality goals ?
  - What are the quality goals ?

# Questions ?

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